Antenna Radiation Pattern Measurement System for Automotive Radar

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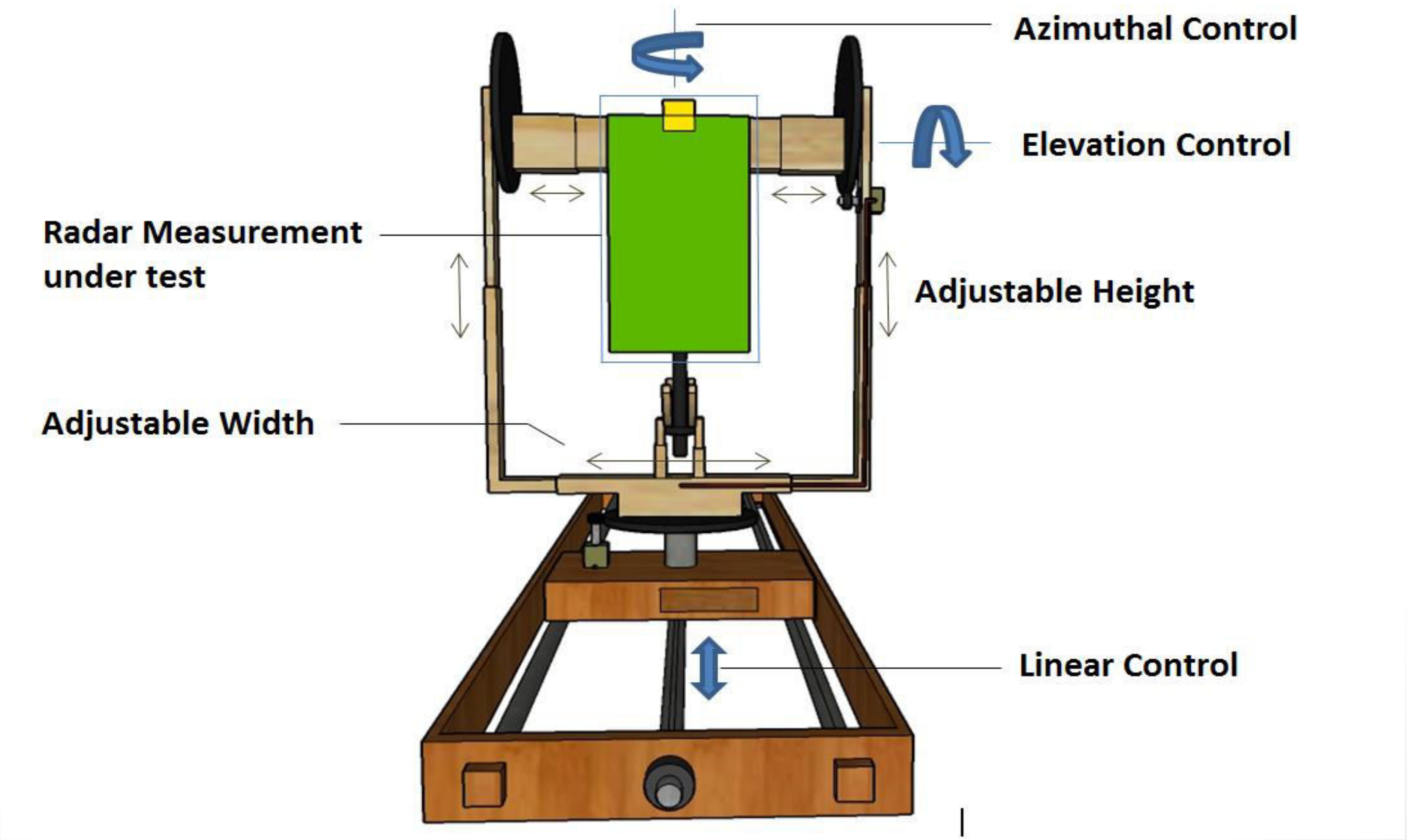
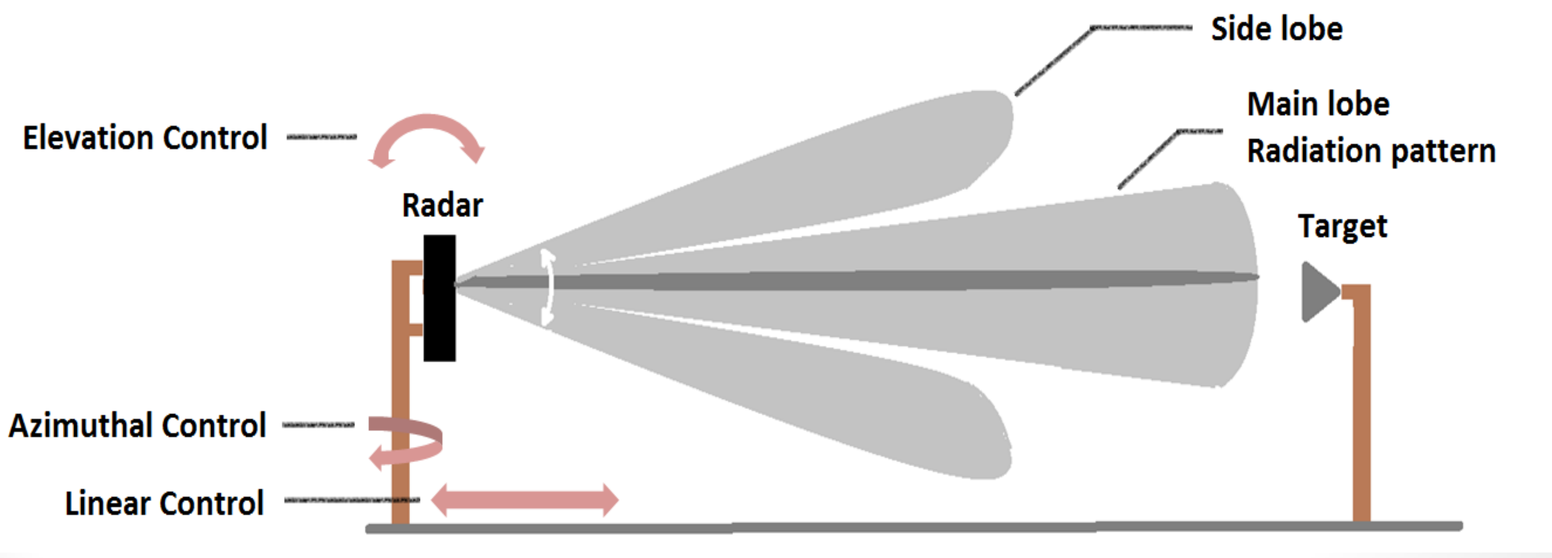
Motivation

- Manually controlling radar position for testing is time consuming and cumbersome.
- Use of radar positioning system can significantly reduce the testing time and provide accurate position measurements.

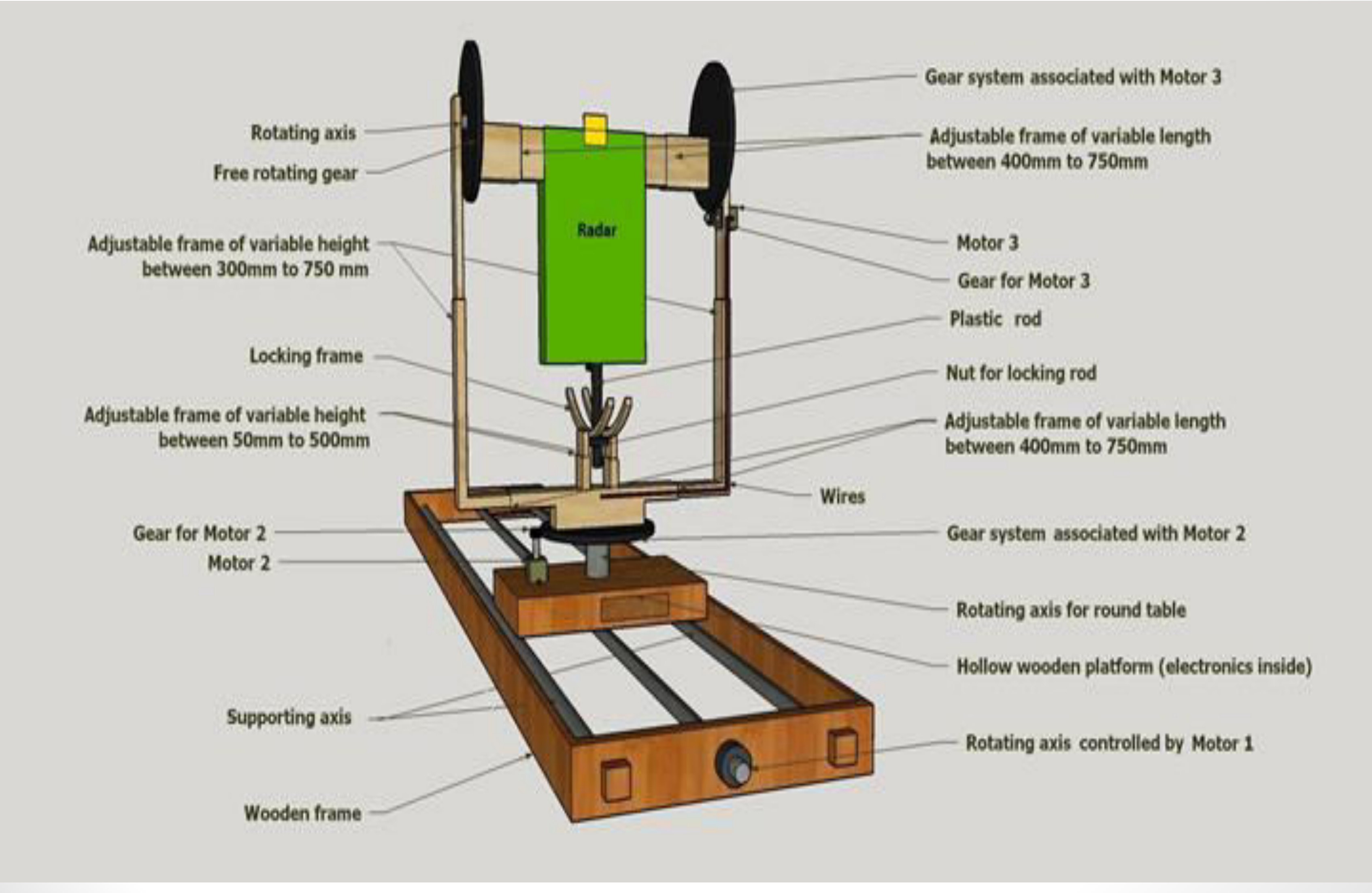


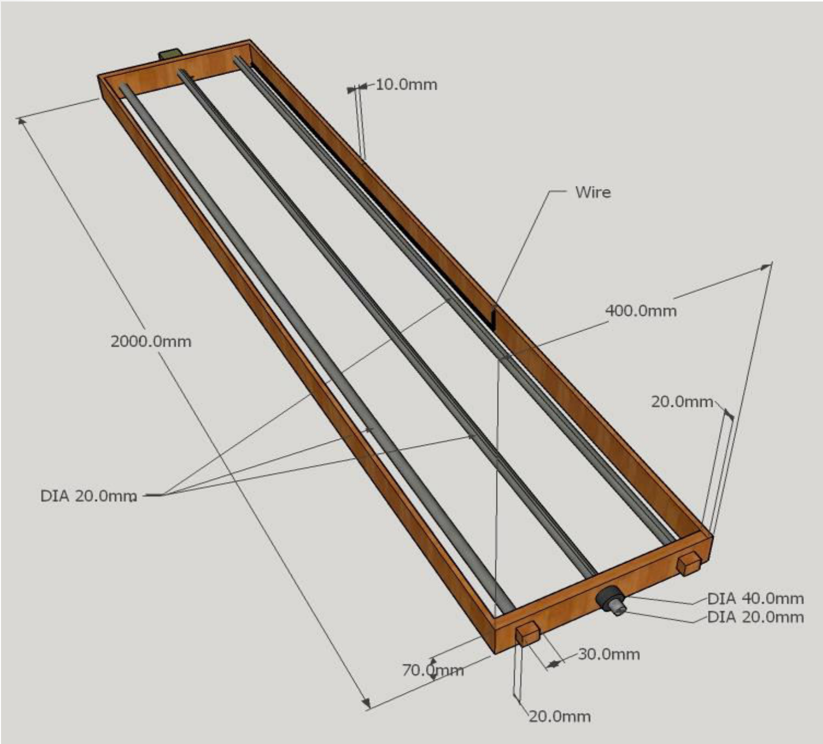
Introduction

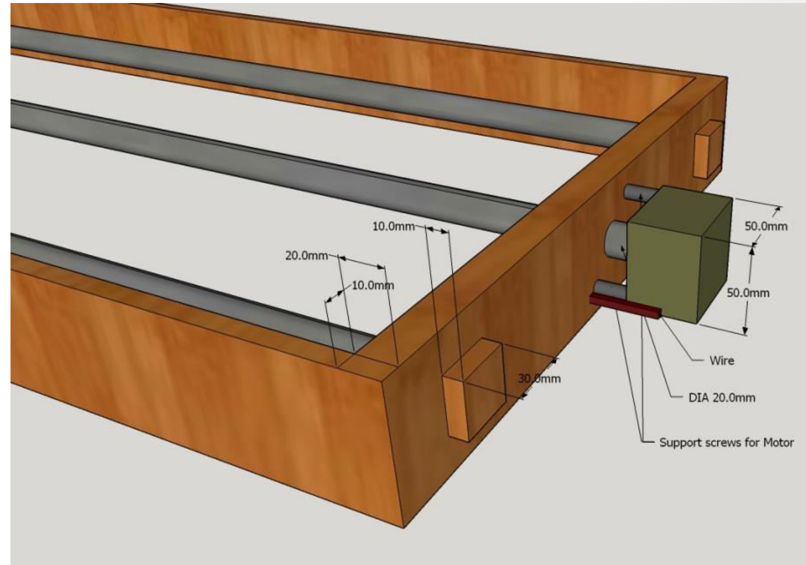
- The project aims to develop an automatic radar positioning system that can control 3D position of the radar antenna using a desktop application.
- The system should be capable of positioning the radar at angular error less than 1^o and range error less than 1 mm.



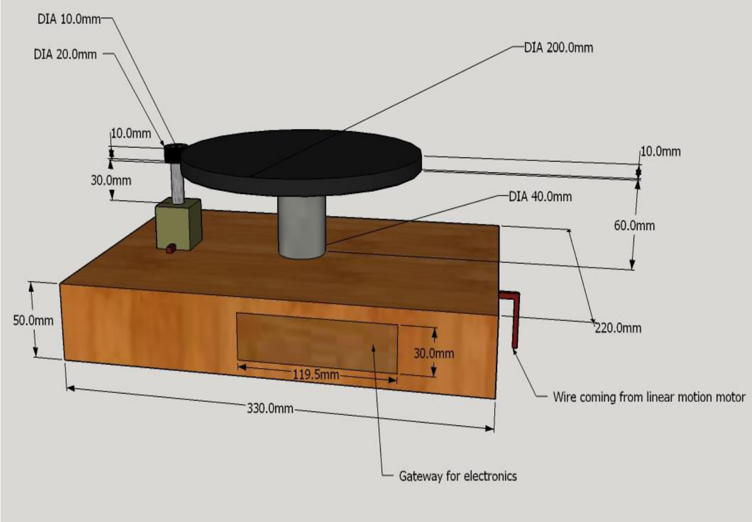
Description of Mechanical Structure

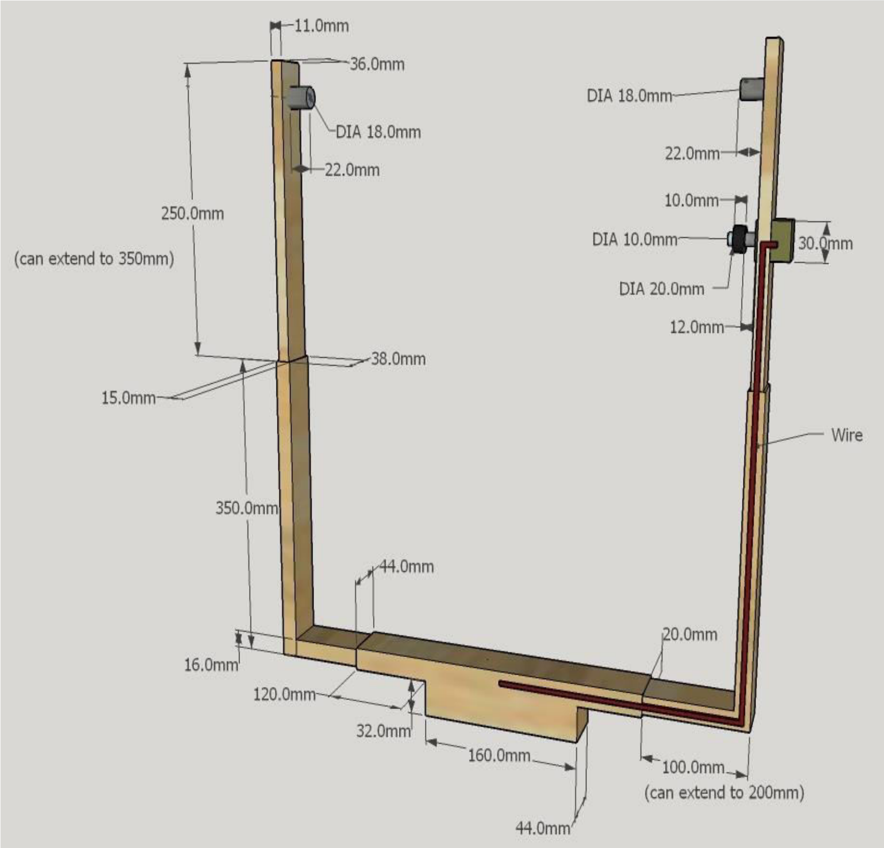




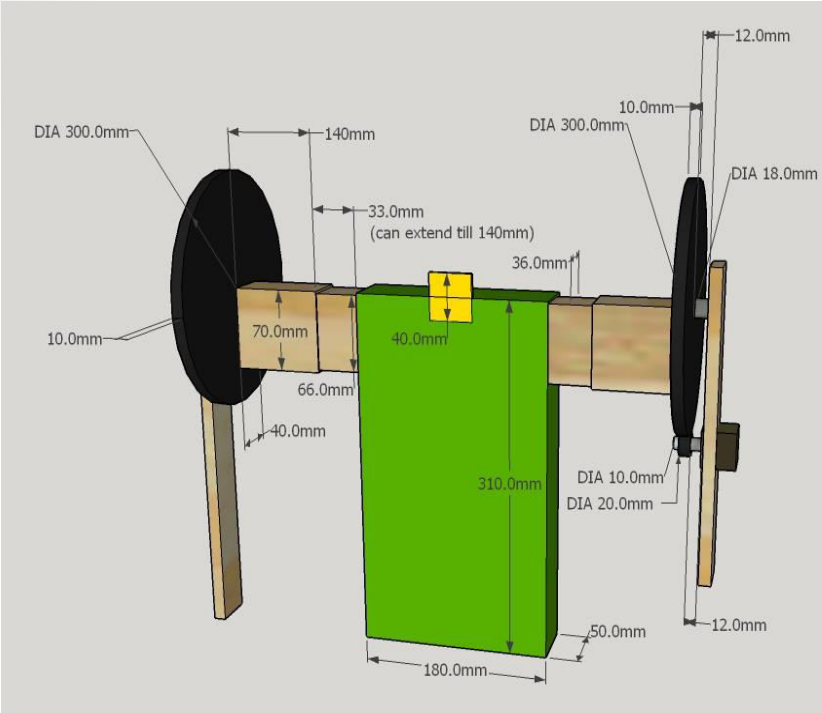


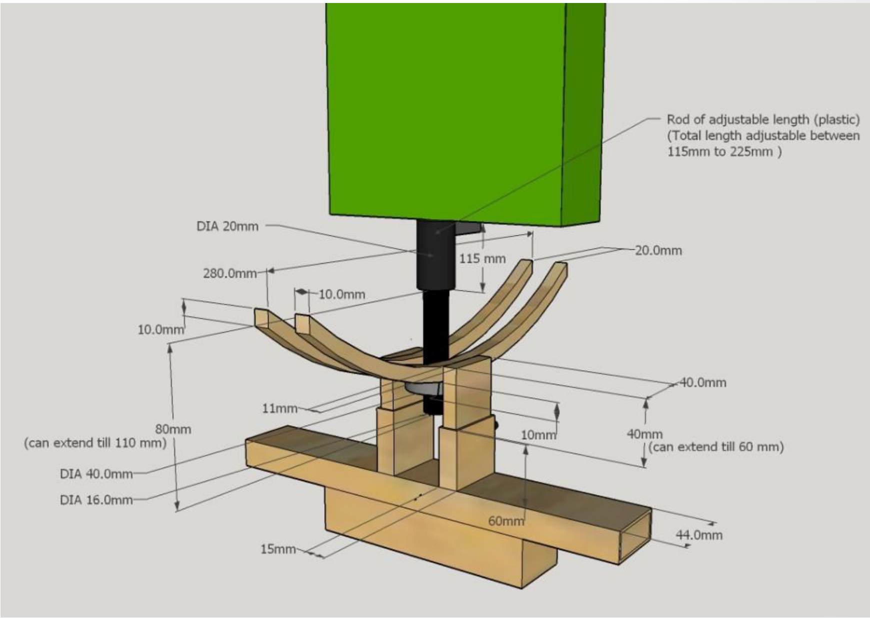
- **Linear position control** - To control the range of the antenna from the target. It allows range adjustment for a maximum of 2 meters from the reference position with range error less than 1 mm.
- **Safety features** - To keep the mechanical structure safe from wrong input positions, the GUI and software codes are designed to reject input positions that are out of bounds and report an error message to the user.





- **Azimuthal position control** - To control the azimuthal angle of the antenna (horizontal plane) with respect to reference. Azimuthal position is restricted from -80^o to 80^o from the reference position.
- **Extendable mechanical frame** - To adjust the height of radar antenna and the distance of radar from the frame.





- **Elevation position control** - To control the elevation of the antenna with respect to reference. Polar angular position is restricted from -50^{o} to 50^{o} from the reference position.
- **Vertical locking system** - To lock the vertical position when using same elevation position.

Actual Mechanical Design

Project Modules Overview

Mechanical Structure Design

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Hardware Interfacing and Software Coding

↓

Measurement and Analysis

↓

Mechanical Construction Follow Up

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Documentation and Project Close-out

Mechanical Structure Design

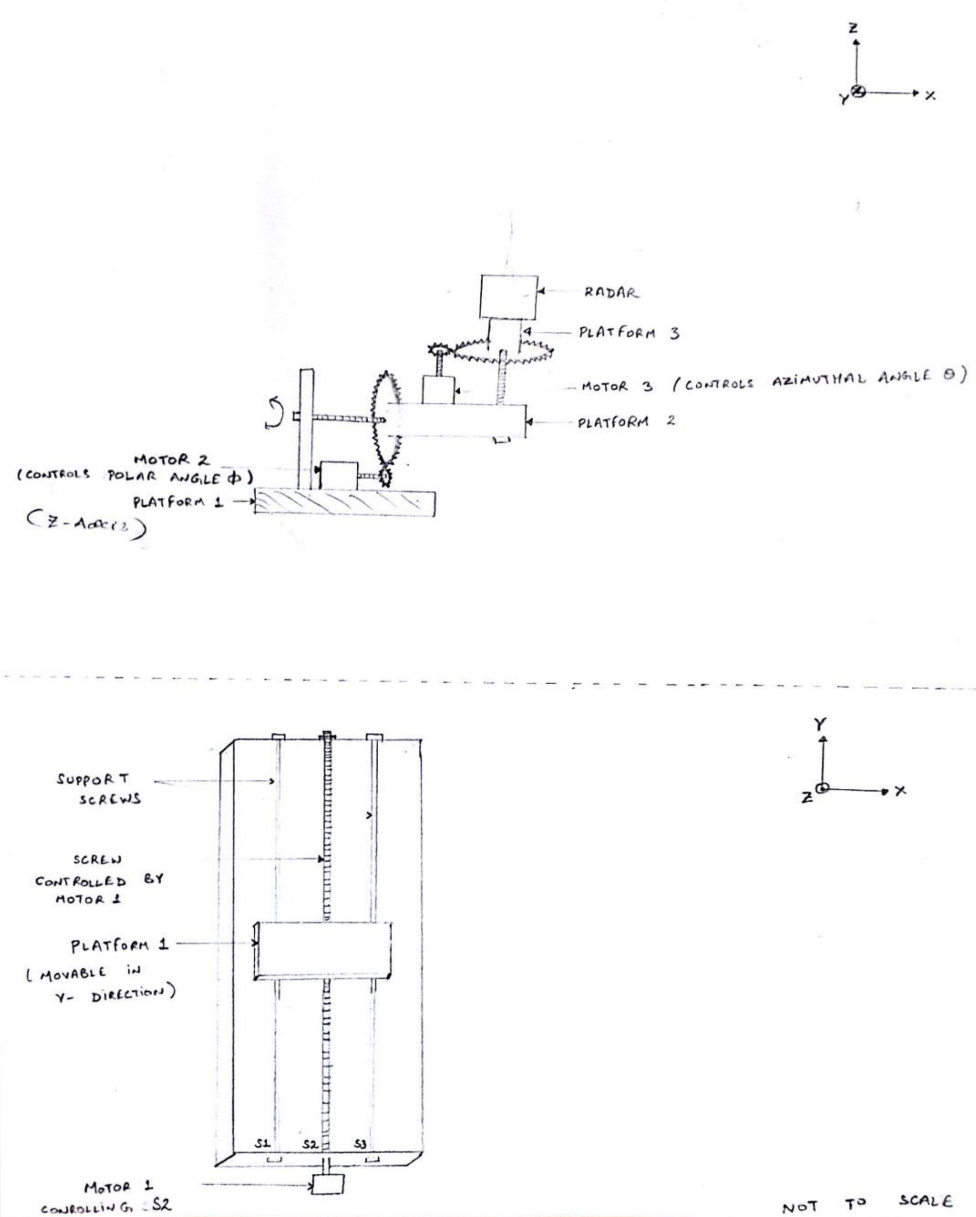
- The module started with basic conceptual design development of the radar positioning system.

- Many hand drawn designs were discussed, followed by computer aided designs (software used - Google SketchUp [1]).

- The stepper motors used is having a stepping angle of 1.8^{o}. To decrease angular position error below 1^{o}, a gear system arrangement with gear ratio 6.167 was used.

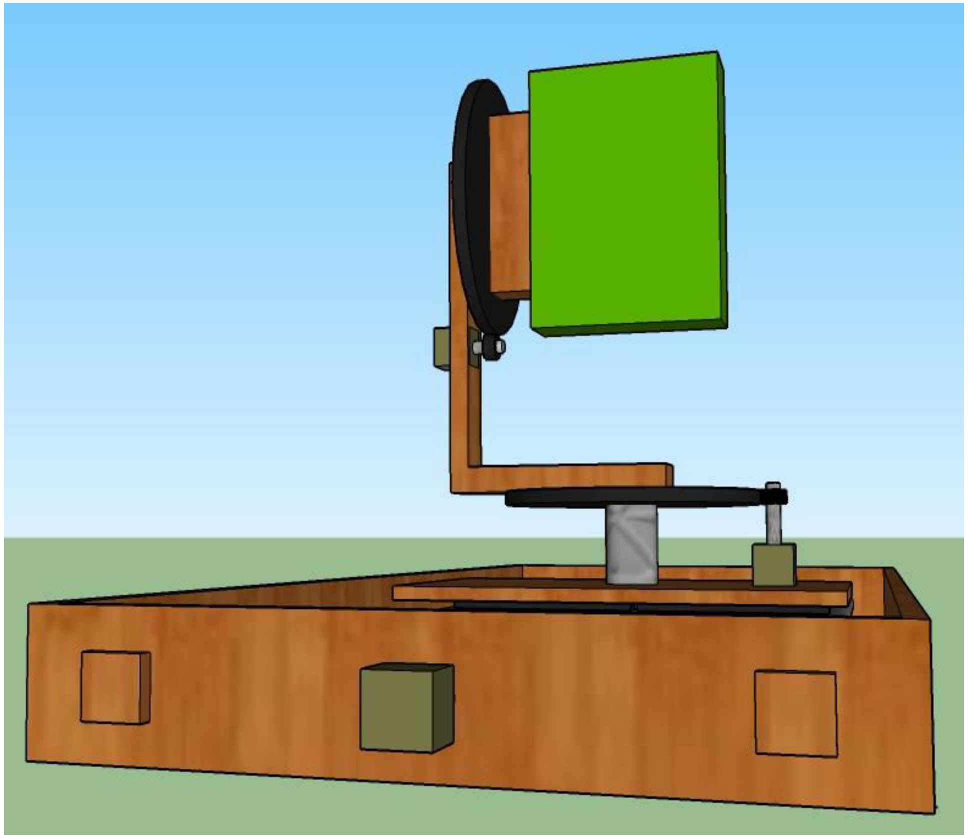
- The gear system also decreased the torque requirement on the stepper motor.

Initial Designs



Design shown on left would require computation of true angular and range positions whenever Motor 2 is rotated. This would require extra processing power and introduce delay in the system.

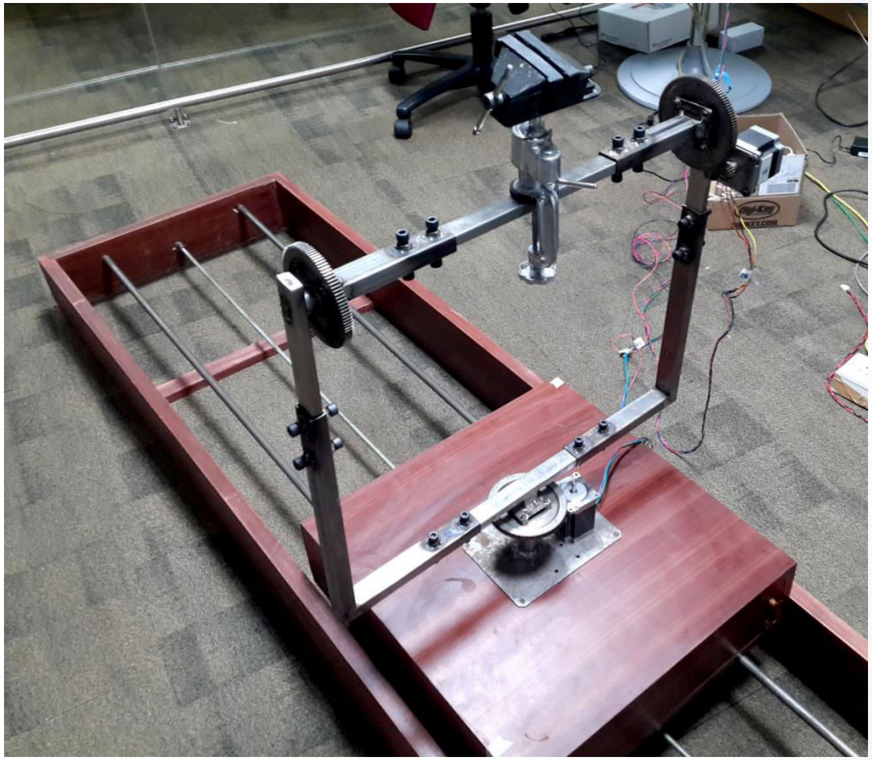
Initial Designs



Design shown on left has an L – shaped frame. This would introduce instability on the horizontal turn table and may lead to errors in position. This problem was solved by using a balanced U-shaped structure in the final design that balances load on the horizontal turn table.

Key Features

- Angular position error less than 1^{o} in both horizontal and vertical plane.
- Range accuracy of 1 millimeter.
- Maximum range adjustment up to 2 meters.
- Easy to use graphical user interface.



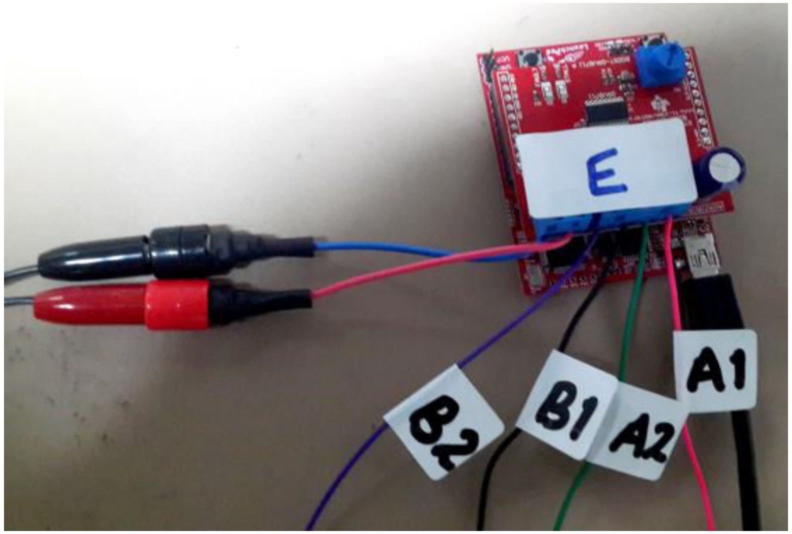
Study Phase

- To drive the stepper motors, the motor drivers with sufficient current supplying capacities need to be used. DRV8711 motor drivers provide sufficient current for the selected stepper motors.

- To control the PWM pulses needed to drive DRV8711 and to control the GUI, a microcontroller with sufficient CPU capacity is required. MSP430G2553 fulfills this requirement and MSP430-G2 + DRV8711 combination was decided to control the motors.

- This combination is implemented by using BOOST-DRV8711 Booster Pack [2] + MSP430G2553 LaunchPad [3] bundle for each stepper motor.

Study Phase



- BOOST-DRV8711 Booster Pack + MSP430G2553 LaunchPad bundle comes with easily modifiable software codes as a CCS project.
- The example project also includes an example GUI made with GUI Composer.

Hardware Interfacing and Software Coding

- The preliminary trial GUI was prepared (using GUI Composer) for analysis.

- After successful completion of testing with single stepper motor, three GUIs were made and customized to control linear, azimuthal and elevation positions.

- Debug Server Scripting (DSS) techniques were used to initialize connections to the MSP430 LaunchPads.

- The executable files for each GUI are then combined to run by single batch file.

Mechanical Construction Follow Up

- The mechanical structure made was analyzed carefully to check for error budgeting.
- Connection wires were placed and pre-final system testing was done.
- The torque requirements and power consumptions were verified with the estimated values.
- Cost of the system was analyzed and market study was done.

Error Budgeting

(To be verified by practical measurements)

No. of teeth on motor gear = 18
No. of teeth on load gear = 111
Gear Ratio = 6.167
Motor Step angle = 1.8^o
Default micro-stepping = 1/256
Motor Step accuracy = $\pm$ 5 %
For 1^o indexing mode,
No. of teeth moved = 111/360 = 0.308
Motor movement = 360/18 * No. of teeth moved = 6.167^o
No. of motor steps = 6.167/1.8 = 3.426
Error in motor movement = $\pm$ 0.05 * 3.426 * 1.8 = 0.308^o
Error in position = $\pm$ Error in motor movement/Gear Ratio = 0.05^o
Mechanical error (approximated) = $\pm$ 20 %
Error in teeth position = $\pm$ 0.2
Error in position in degrees = $\pm$ 0.649^o
Worst case error = $\pm$ 0.7^o

Torque Requirements

(To be reviewed by practical measurements)

Elevation Control (Estimated)

Moment of Inertia = 0.13 kg m^2
Load Torque = 0.9 Nm
Acceleration Torque = 0.8 Nm (taking Speed = 360^o/sec)
Total Torque required = 1.7 Nm = 241 oz-in
Gear Ratio = 6.167
Torque required on Motor 3 = 39.1 oz-in

Azimuthal Control (Estimated)

Moment of Inertia = 1.24 kg m^2
Load Torque = Negligible (compared to acceleration torque)
Acceleration Torque = 3.9 Nm (taking Speed = 180^o/sec)
Total Torque required = 3.9 Nm = 553 oz-in
Gear Ratio = 6.167
Torque required on Motor 3 = 89.67 oz-in

Torque Requirements

(To be reviewed by practical measurements)

Linear Control (Estimated) **(**Ball Screw Drive)

Lead = 10 mm/rotation

Preload = 5%

Ball circle diameter = 15 mm

Lead angle = 37.8^{o}

Drag Torque = Negligible (compared to driving torque)

Driving Torque = 0.7 Nm

Back driving Torque = Negligible (compared to driving torque)

Total Torque required = 0.7 Nm = 100 oz-in

Cost Analysis

Serial No.	Particulars	Quantity	Price Rs	Amount Rs
1	DRV8711 Booster Pack	3	1500	4500
2	MSP430-G2 LaunchPad	3	600	1800
3	Gear system	2	6183	12366
4	Mechanical Strucutre	1	17600	17600
5	Stepper Motors	3	4800	14400
6	24 V AC-DC Adapter	3	1440	4320
7	USB Hub	1	810	810

Total - Rs 55,796/-

*Conversion Rate: 1 USD = Rs 60

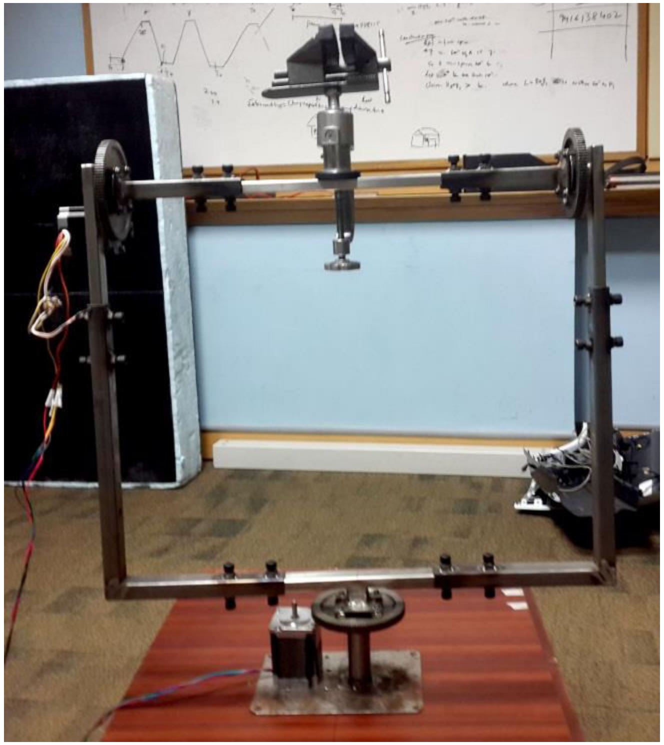
Comparison with other methods/products

(To be reviewed after practical analysis)

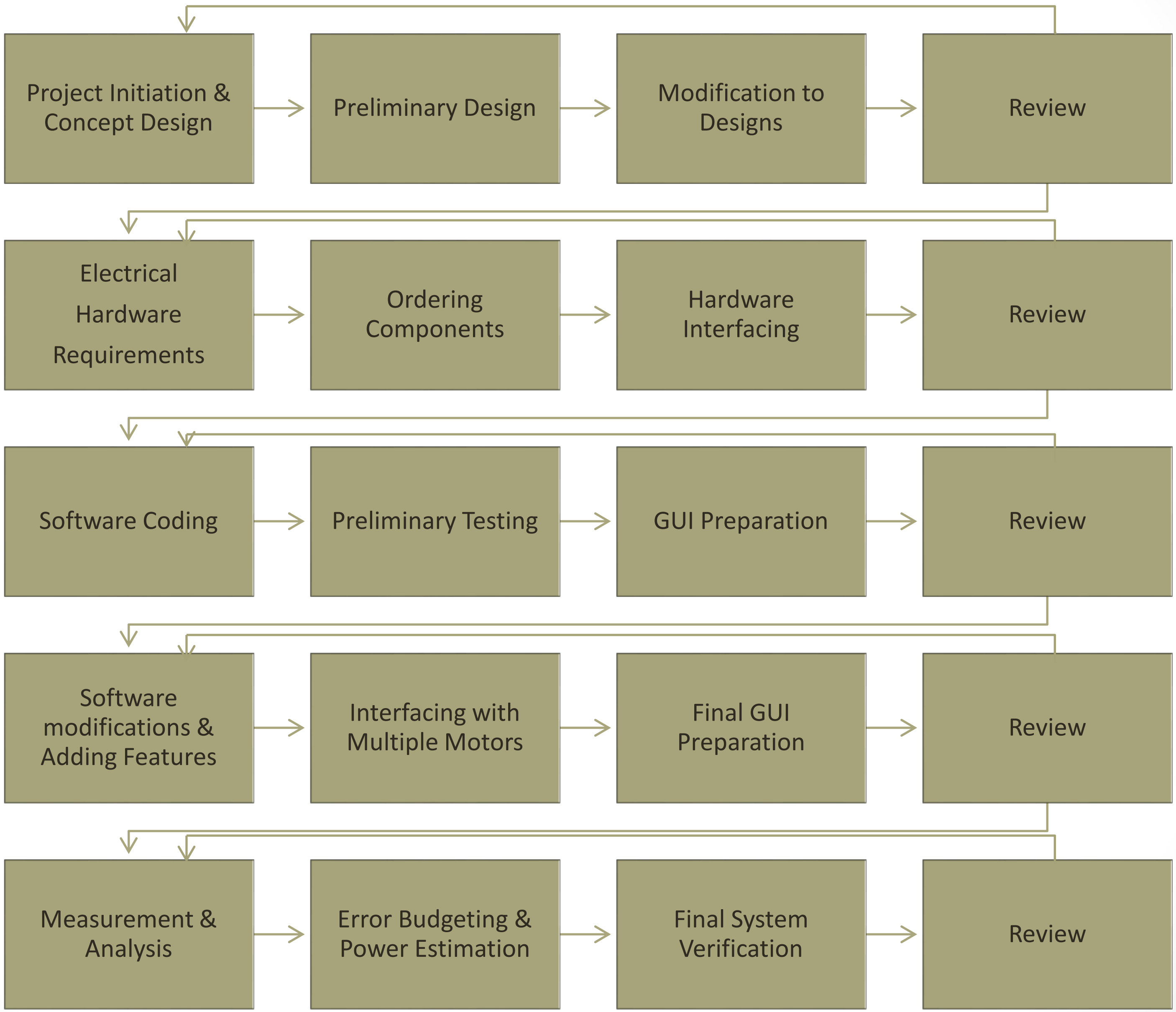
Features	TI Radar Positioning System	Manual positioning	ETS-Lindgren 2020 Multi-Axis Positioner (MAPS) [13]
Accuracy	Very Good	Poor	Excellent
Automation	Excellent	Poor	Excellent
Load capacity	Good	Good	Excellent
Testing time	Excellent	Poor	Very Good
User friendly	Excellent	Poor	Excellent
Cost	Very Good	Excellent	Poor
Range control	Yes	No	No
Adjustable Height	Yes	Yes	No
Adjustable Width	Yes	Yes	No

Project Close-out

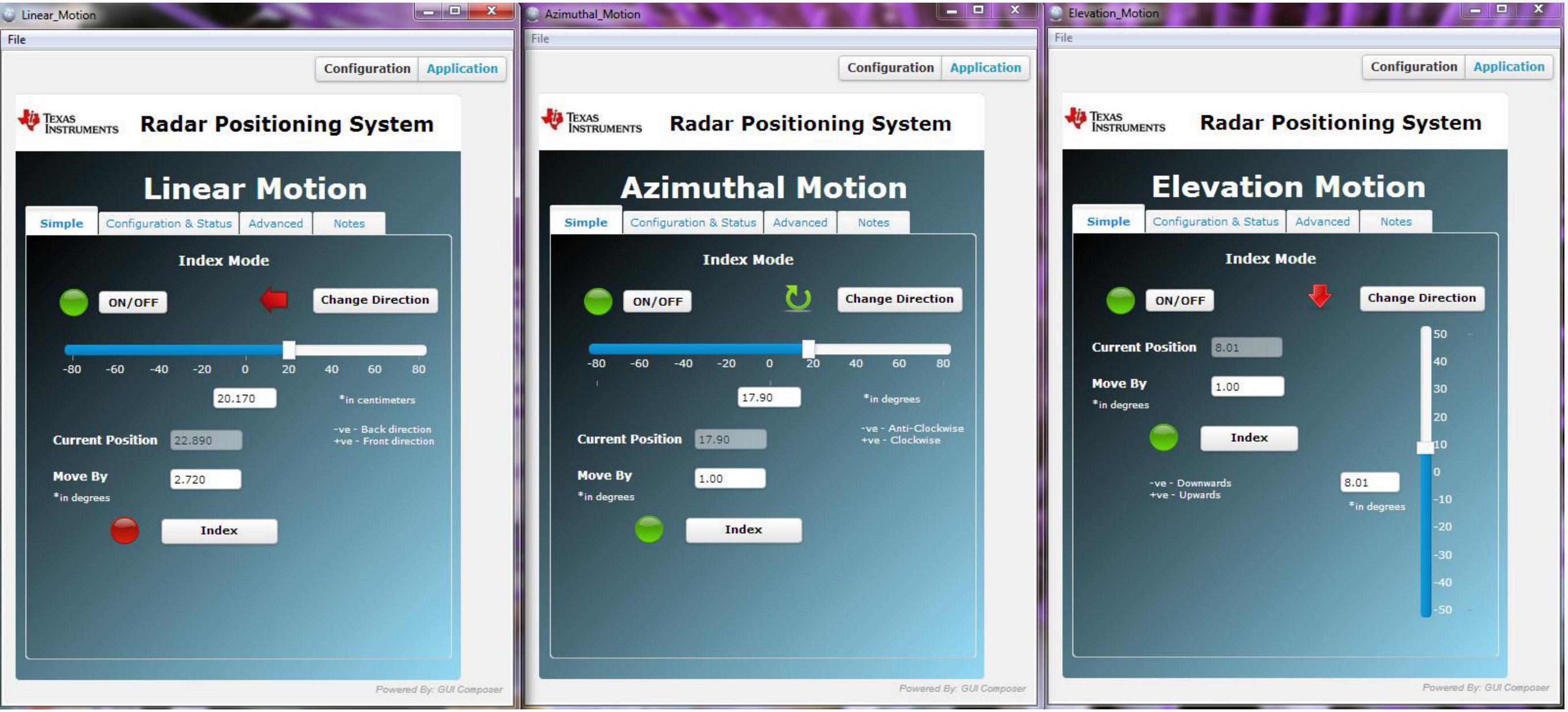
- Final testing was carried out in this module.
- Software resources were compiled and documented.
- Trial user feedbacks were reviewed.



Process Summary



Graphical User Interface



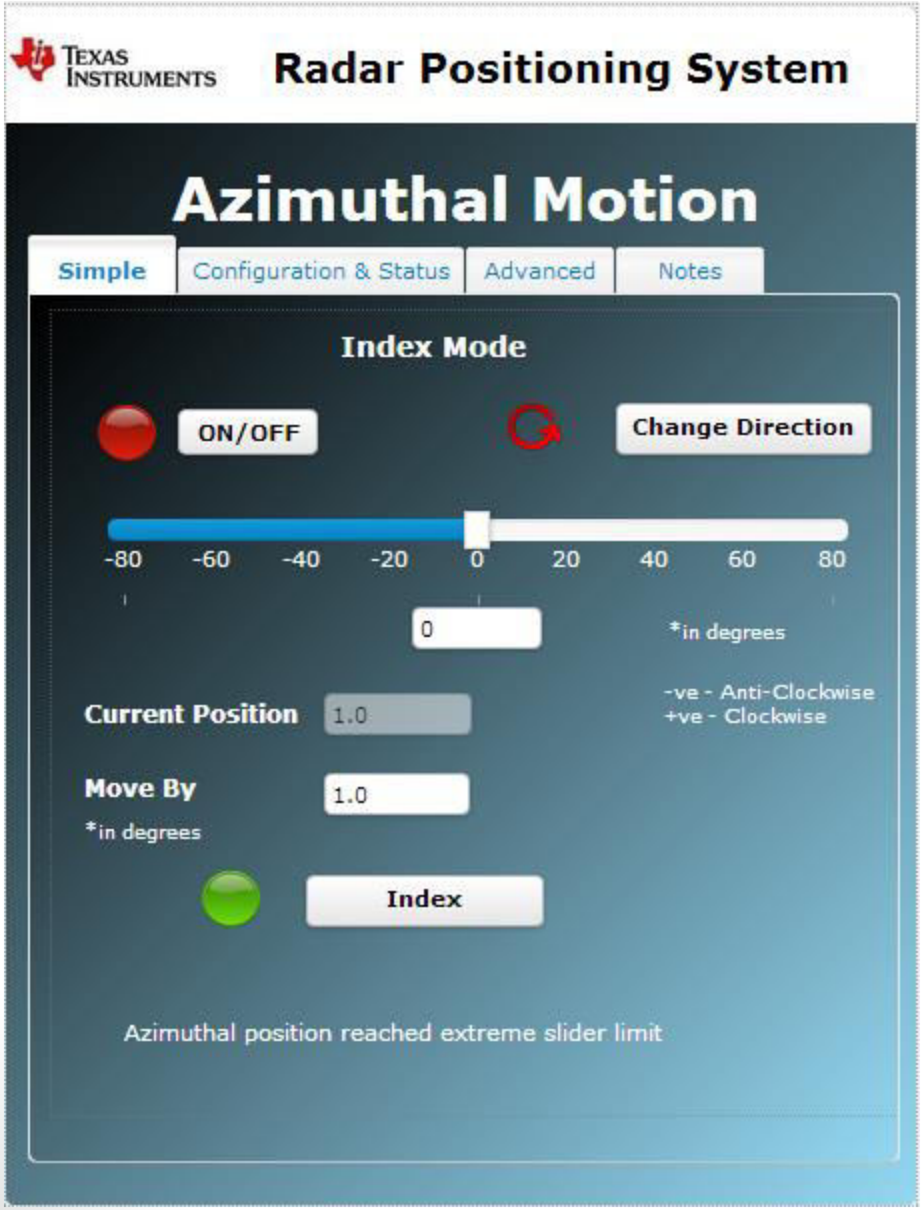
Each of the three GUIs have four tabs –

- **Simple** - Basic control operations and indexing options.
- **Configuration & Status** - Status light indicators, current settings, position reference and return to default position.
- **Advanced** - Change stepper motor profile, degree of stepping, decay mode, speed and acceleration.
- **Notes** - Quick notes for user reference.

Simple

- ***ON/OFF*** – To power motor ON (holding torque present) or OFF (no holding torque).
- ***Change Direction*** – Toggle direction of motion.
- ***Slide Control*** – Sets the destination position.
- ***Current Position*** – Specifies the present angular/linear position with respect to reference.
- ***Move By*** – To increment the position by a specified field. Enter the number of degrees/cm to increment the present position in the chosen direction and press Index button.
- ***Index*** – Moves the position to new position set by Slider or Move By field.

Simple

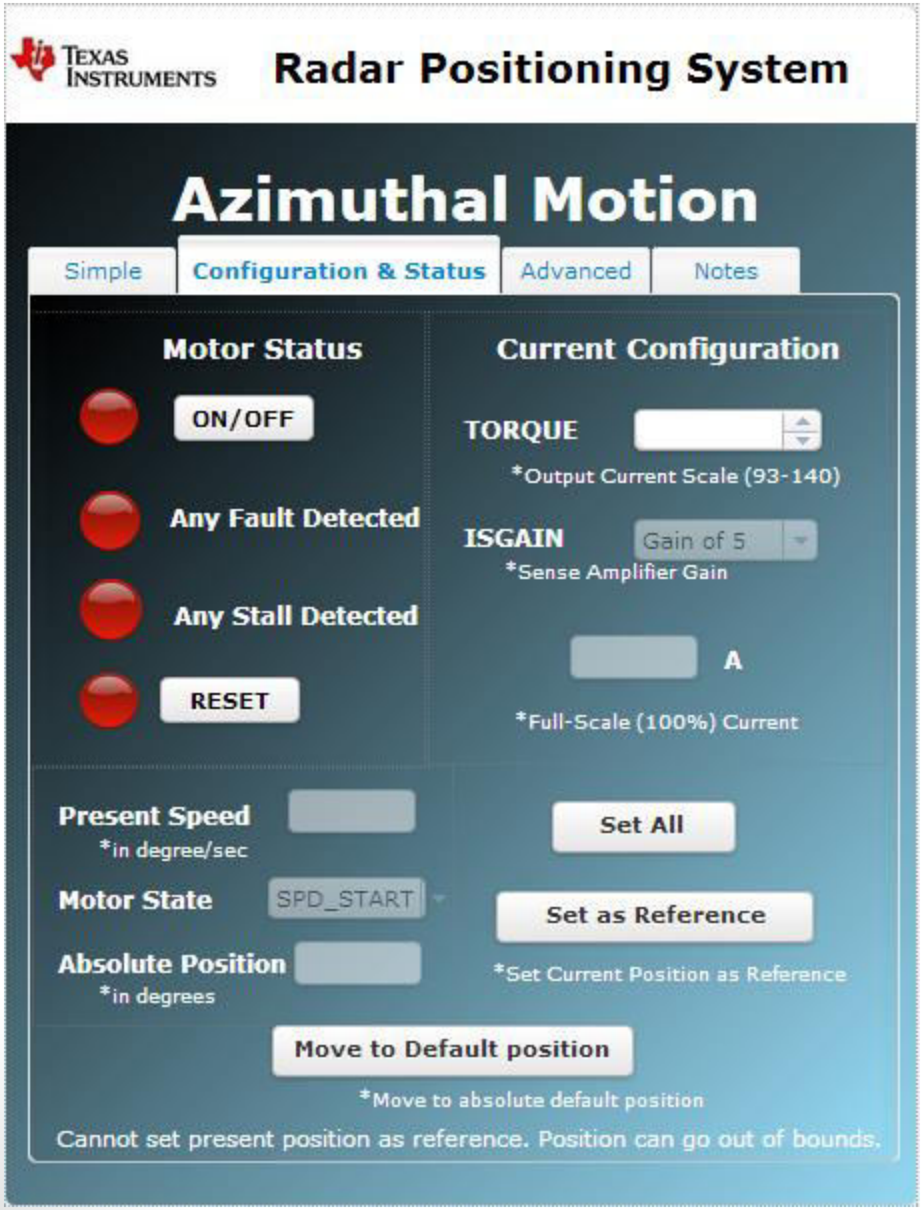


- Easy slider control.
- Position can also be controlled by specifying step size.
- Notifications to user when extreme position limits reached.

Configuration & Status

- ***ON/OFF*** – To power motor ON (holding torque present) or OFF (no holding torque).
- ***Any Fault Detected*** – (Green) Normal condition, (Red) Fault in Driver.
- ***Any Stall Detected*** – (Green) No stall, (Red) Motor stall.
- ***RESET*** – To reset any fault or stall detect.
- ***TORQUE*** – To set output current from 2 A to 3 A.
- ***ISGAIN*** – To change the sense amplifier gain (Default : Read only).
- ***Full Scale Current*** – Displays the full scale current of the motor. Can be adjusted by changing TORQUE field.
- ***Present Speed*** – Displays the present running speed of the motor.
- ***Motor State*** – Displays the motor state – start, acceleration, deceleration, hold, etc.
- ***Absolute Position*** – Displays the absolute position.
- ***Set All*** – To set the current configured using TORQUE field.
- ***Set as Reference*** – Makes the present position zero and sets as reference.
- ***Move to Default Position*** – Moves the motor to absolute zero position.

Configuration & Status



- Motor status indicates any stall or fault detect.
- Current can be modified by changing Torque field.
- Present speed, absolute position and motor state indicators.
- Set the present position as reference.
- Move to default position at the end of measurements.
- Safety features predesigned to reject inputs out of bounds.

Advanced

(For Advanced users only)

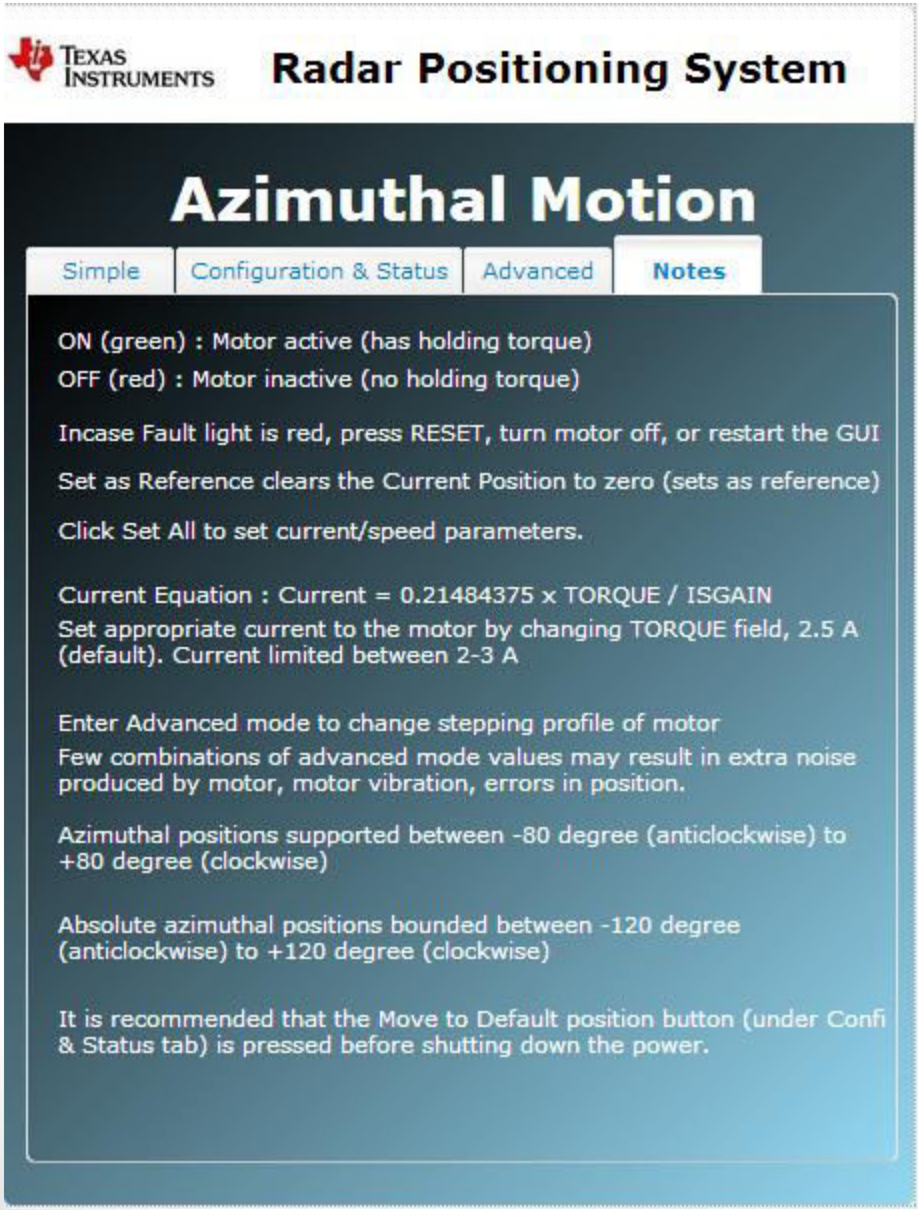
This section controls the stepping profile of the motor.

- ***Start/Stop Speed*** – To set the starting/stopping speed of the stepper motion profile.
- ***Target Speed*** – To set the final speed of the stepper motion profile.
- ***Accel Rate*** – To set the acceleration rate of the stepper motion profile.
- ***Step Mode*** – To set the degree of microstepping of the stepper motor.
- ***Decay Mode*** – To set the current regulation method.
- ***Angle/Linear Multiplier*** – Multiplies the step movements by this field (Gear ratio or Lead). This is used to port the angular movement of motor to the angular/linear movement of radar module.
- ***Set All*** – To set the stepping profile parameters.
- ***Firmware Version*** – Displays the current firmware version of the application.

Advanced

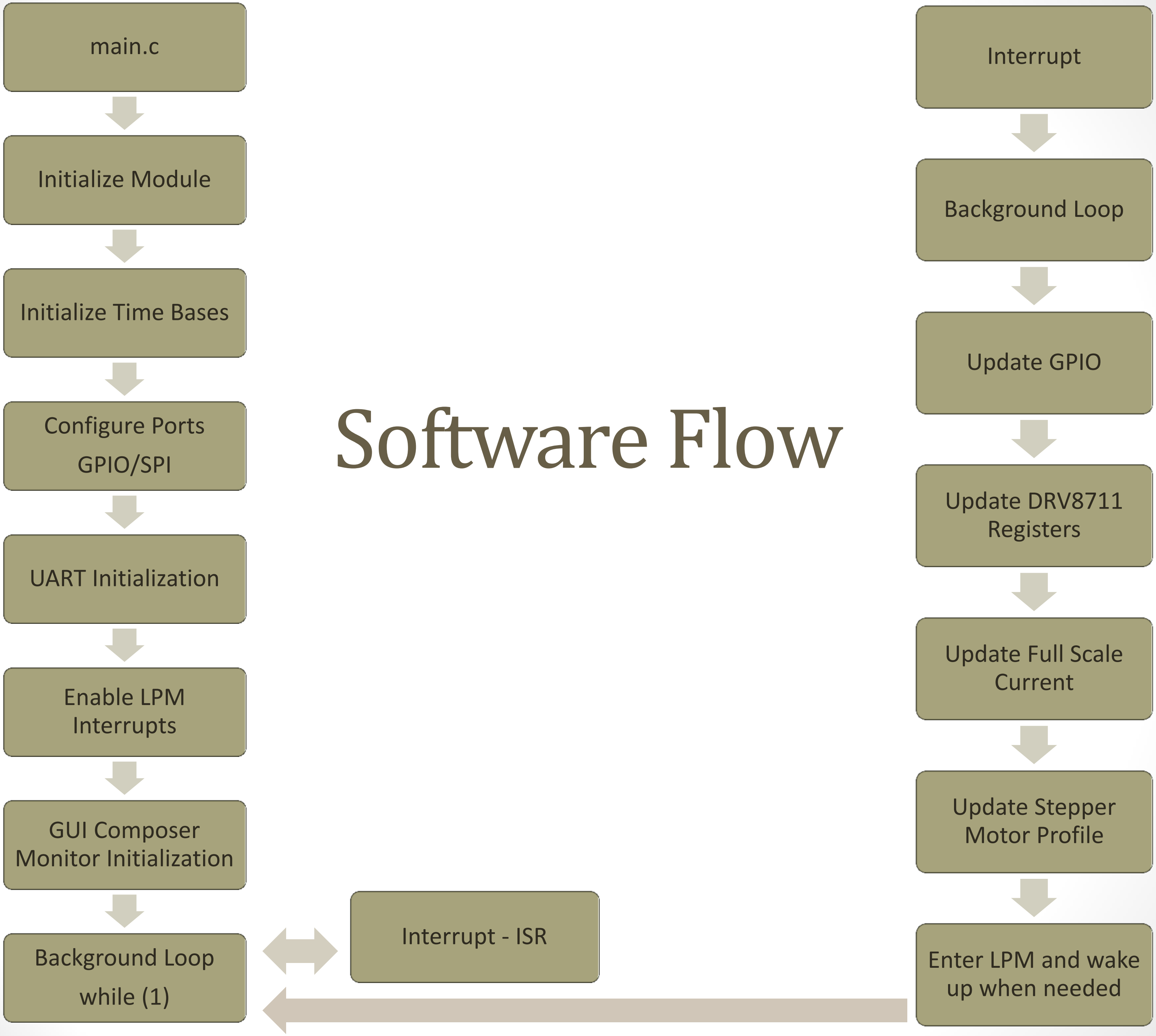
- For advanced users, stepping profile can be changed.
- Change speed, acceleration, microstepping and decay mode.
- Angle multiplier to fix the gear ratio translation of position accurately.
- System can be calibrated directly from GUI.

Notes



- Quick reference notes to user for easy control.

Software Flow



Future Improvements

- Using three GUIs for individual motors is not user friendly and interactive. Unifying it into a **single GUI** is possible using different software or in future versions of GUI Composer.
- **Automated spectrum capture and position increment** is possible by giving an interrupt vector as input through SPI. This can be incorporated by either modifying the utility.c code or through DSS.
- Mechanical frame made of metal obstructs with the target measurements. **Absorbers** can be placed on the metal frame or the mechanical frame can be made of fiber reinforced plastic or PVC that do not interfere with the spectrum measurements.
- An extra **Infrared or Bluetooth** module can be extended to the MSP430 LaunchPads to allow controlling the position through remote control.

References

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10. Machine design, http://machinedesign.com/mechanical-drives/high-accuracy-linear-positioning-systems-part-1

Thank You